Global Precipitation Mission (GPM)
Ground Validation System
Operations Concept

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Goddard Space Flight Center
Greenbelt, Maryland 20771

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TABLE OF CONTENTS

1. GVS Overview 1
1.1 Introduction 1
1.2 GVS Definition 1
1.3 GVS Conceptual Framework 2
1.4 Applicable Documents 3
1.5 Reference Documents 3
1.6 Document Organization 3
2. General Functions of the GPM GVS 5
3. GVS Archive and Distribution Function 6
4. Field Campaign and Product Generation (FCPG) Function 7
4.1 Overall FCPG Operations 8
4.2 FCPG Product Generation Operations 10
4.3 Site Selection and Instrument Deployment 12
5. Validation Network (VN) Function 13
5.1 VN System Description 13
5.2 Data Ingest Sub-Function 14
5.3 Data Preprocessing Sub-Function 15
5.4 Data Post-Processing and Analysis Sub-Function 16
5.5 Scheduled and Interactive Tasks Sub-Function 22
5.6 VN Performance 23
6. GVS Metrics Database Function 24
7. GVS Interfaces 25
7.1 Precipitation Measuring Mission Science Team 25
7.2 Precipitation Processing System 25
7.3 General Users 25
7.4 GPM Management 25
7.5 Ancillary Data 26
7.6 Long-Term Archive 26
8. Mobile Ka-/Ku-band Radar 27
8.1 Electrical Performance 27
8.2 Physical/Mechanical Performance 27
8.3 Instrument Product Generation 28
8.4 General Instrument Characteristics 28
8.5 GPM Project Contributions to Radar Instrument Operations 29
9. GPM GVS Operational Scenarios 30
9.1 Operational Data Flow 30
9.2 Pre-launch Algorithm Development 30
9.3 Post-Launch Product Validation 31
10. Acronyms and Symbols 33

FIGURES AND TABLES

Figure 1-1. GPM Mission Architecture.. 2
Figure 1-2 GVS Operational Data Flow.. 4
Figure 4-2. Illustration of the EOP and IOP concepts. 7
Figure 4-3. illustration of the Instrument Deployment and Product Generation functions during EOPs and IOPs.. 9
Figure 5-1. Overview of major functions and processes of the GPM GVS VN. 14
Figure 5-2. Example scatterplot of WSR-88D vs. TRMM PR attenuation-corrected reflectivity. From Liao, et al. (2001).. 19
Figure 5-3. Example time series of WSR-88D – TRMM PR attenuation-corrected reflectivity. From Anagnostou et al. (2001). 20
Figure 5-4. Example of WSR-88D –TRMM PR attenuation-corrected reflectivity difference vs. PR reflectivity category. From Anagnostou et al. (2001)................. 20
Figure 5-2. Example vertical profiles of WSR-88D and TRMM PR reflectivites. From Bolen and Chandra (2000).. 21

1. GVS Overview

1.1 Introduction

This document defines the Operations Concept for the Global Precipitation Mission (GPM) Ground Validation System (GVS). It includes a high-level description of the GVS, its interfaces with other entities, and some expected operational scenarios. It serves as a roadmap for GVS development and testing.

Overall, the GPM mission has defined a series of scientific objectives that include improvement in predicting terrestrial weather, climate, and hydrometeorology through a better observational understanding of the global water cycle. The GVS contributes to the GPM mission by providing data and observations needed for precipitation retrieval algorithm development in the pre-launch time frame, and by providing independent evaluation of precipitation products following the launch of the GPM Core satellite, schedule for launch in July 2013. For its part, the GVS applies three overarching approaches to validation of GPM. These approaches, and GPM GVS contributions to them, are defined in the *GPM GVS Science Implementation Plan*:

- *National networks:* GPM GVS contributes calibrated ground observations from operational and research instruments, regional and continental scale precipitation and hydrological products with associated error models, and other related activities on large regional or continental scales
- *Physical process studies and field campaigns:* targeted ground and aircraft measurements of cloud microphysical properties, precipitation, radar reflectivity, and radiances; plus other relevant observations on local to regional scales
- *Integrated hydrometeorology applications:* stream gauges and other hydrological measurements for basin-scale water budget studies.

1.2 GVS Definition

The Global Precipitation Measurement (GPM) mission is a partnership between the National Aeronautics and Space Administration (NASA) and the Japanese Aerospace Exploration Agency (JAXA). NASA's Goddard Space Flight Center (GSFC) has the lead management responsibility for GPM mission. The GPM mission definition includes the following elements:

- GPM Core satellite carrying the JAXA-provided Dual-frequency Precipitation Radar (DPR) and a NASA-provided, passive GPM microwave imager (GMI)
- A GMI instrument intended for flight on a Low-Inclination Orbit (LIO) satellite provided by a partner to be determined, and schedule for launch in 2015
- A Precipitation Processing System (PPS) to generate near-real-time precipitation products and a final time series of global precipitation measurements
- A Mission Operations System for the operation of the NASA-provided spacecraft
- A Ground Validation System (GVS), consisting of several system elements employed in the independent validation of the instruments on the GPM core satellite and the associated data products generated from them.

The high-level roles within the GPM mission, and the GVS portions of them, are illustrated in Figure 1-1.

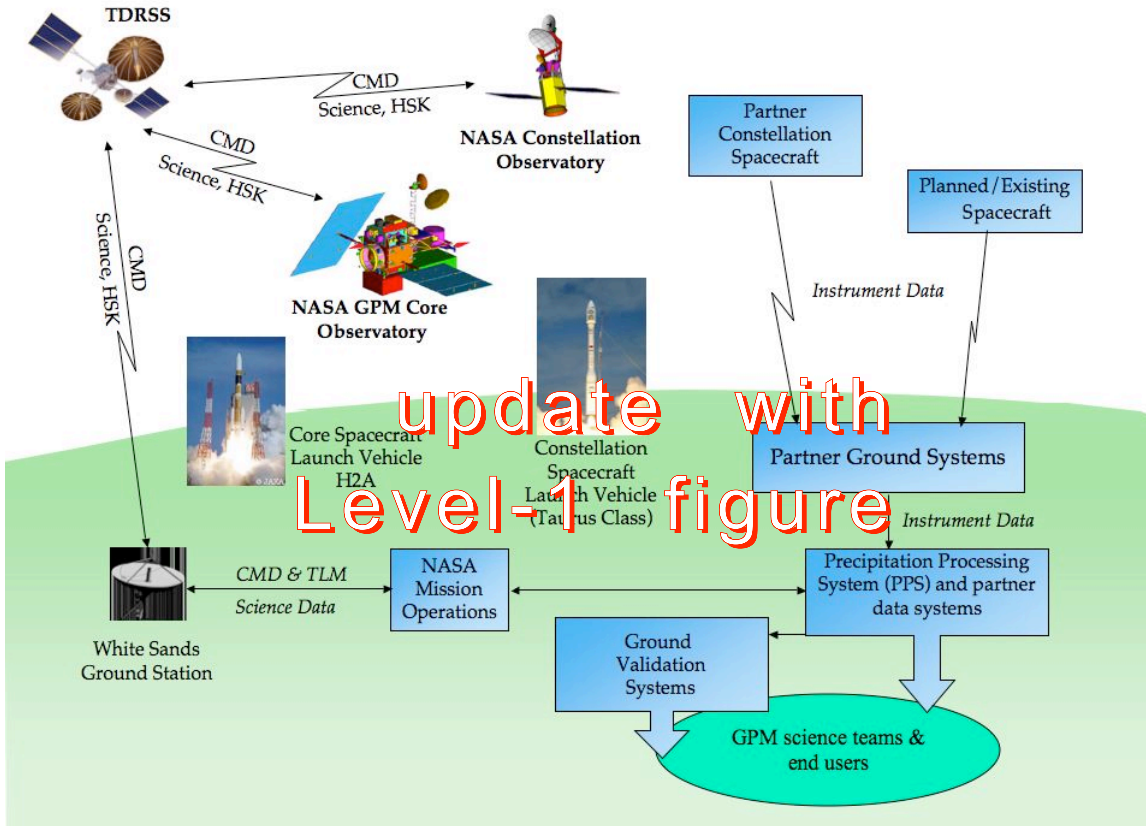

Figure 1-1. GPM Mission Architecture

1.3 GVS Conceptual Framework

The conceptual framework for GVS is based on the notion of statistical and physical validation of GPM satellite data products. *Statistical validation*, often referred to as "ground truth," is used to identify random and systematic errors in the satellite data products. *Physical validation* is concerned with understanding the origin of these errors. In the GPM GVS, physical validation will verify the assumptions of the radiative transfer models at the core of the retrieval algorithms that generate GPM data products.

GVS statistical validation relies primarily on a series of field campaigns that collect meteorological and atmospheric measurements in a variety of precipitation regimes. The field campaigns will be equipped with various ground- and aircraft-based instruments to make direct and remote sensing measurements. The operations concept for the Field Measurements and Product Generation function is described in Section 4 of this document.

Additional data for GVS statistical validation are provided by the GVS Validation Network (VN). This capability matches up ground radar data from the US network of

NOAA Weather Surveillance Radar-1988 Doppler (WSR-88D, or "NEXRAD"). The purpose of the Validation Network is to evaluate the reflectance attenuation correction algorithms of the GPM Dual-frequency Precipitation Radar (DPR) and to identify biases between ground observations and satellite retrievals as they occur in different meteorological regimes. Since the Validation Network will help identify locations where the GPM precipitation algorithms exhibit significant bias and error, the results of the Validation Network will also be used to help direct the selection of field campaign locations for detailed study of the origins of these errors. The operations concept for the GVS Validation Network function is described in Section 5.

Results of GVS statistical validation will be used to drive the physical validation of the radiative transfer models at the core of precipitation retrieval algorithms. The Precipitation Measuring Mission (PMM) Science Team will have principal responsibility for physical validation, using the statistical data and observations provided by the GVS. An example of how this process will work is illustrated by the results from the Canadian CloudSat/CALIPSO Validation Programme (C3VP), which was fielded with GVS and PMM participation during the winter 2006-2007. The C3VP results are being used by the PMM Science team in the validation of Cloud Resolving Models (CRMs) and in the development of snowfall retrieval algorithms.

1.4 Applicable Documents

The following are considered the controlling documents for this operations concept:

- NASA GPM Project Level 1 Requirements.
- NASA Global Precipitation Measurement (GPM) Mission (L2) Requirements Document (420.2-REQS-013001A).

1.5 Reference Documents

The following documents are specifically referenced in this document:

- Global Precipitation Measurement Ground Validation System Level 3 Requirements for a Mobile Ka-/Ku-band Radar
- PPS Level 3 Requirements
- GPM GVS Product Development Handbook
- GPM GVS Science Implementation Plan (draft).

1.6 Document Organization

The GVS operations concept is presented as a set of functions and processes required for GPM GVS instrument observations, VN comparisons, and associated data product generation. The primary functions of the GVS are illustrated in Figure 1-2 and are described in more detail in subsequent sections of this document. The allocation of functions and processes illustrated in the figure and described in this document is not meant to constrain the detailed architecture and implementation plans of the GVS. Rather, the objective of the GVS is to capture all of the necessary functionality of its operation. It is understood that some functions and processes may ultimately be reallocated within the overall GPM GVS.

Section 1 of this document provides an overview and a context-setting summary of the GMP GVS. Section 2 describes the general functions of the GVS. Section 3 describes GVS data Archive and Distribution (A&D) function. The Field Campaign and Product Generation (FCPG) function and Validation Network (VN) function were described briefly above; additional details are provided in Sections 4 and 5. Sections 6 and 7 respectively describe the GVS Metrics Database function and the GVS external interfaces. Section 8 describes the operations of the mobile, two-frequency (Ka-band and Ku-band), dual-polarization radar that will be built and operated by the GVS. Section 9 describes several GVS operational scenarios.

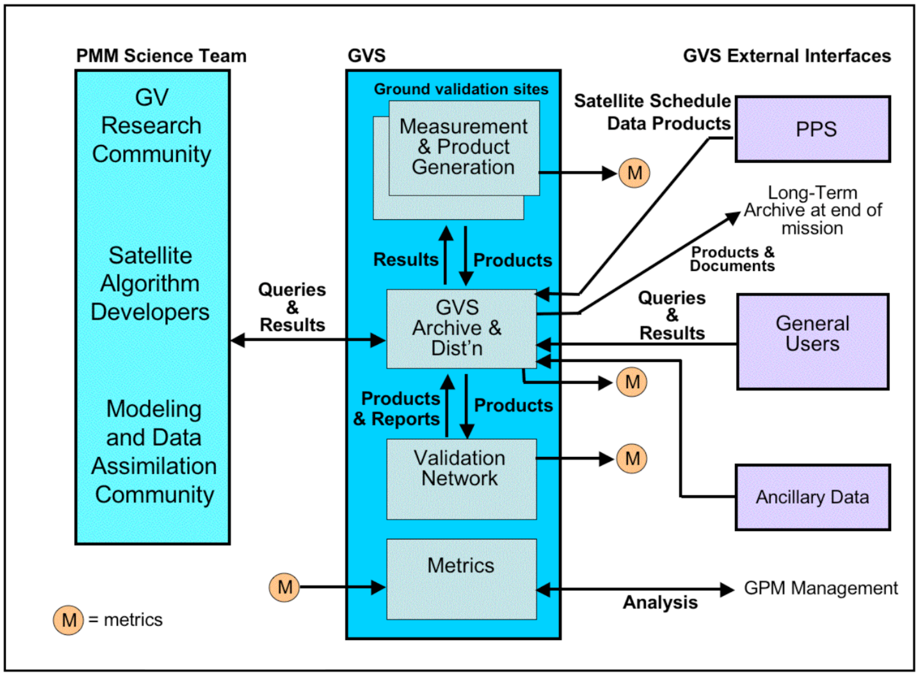

Figure 1-2 GVS Operational Data Flow.

2. General Functions of the GPM GVS

Development and operations of the GPM GVS will be managed by the GPM Project at GSFC. It is a goal for the GPM GVS to re-use current instrumentation, methodologies, best practices, and near-term research results of the precipitation ground validation community to the greatest extent possible. In doing so, the GPM GVS will comply with all of the applicable NASA/GSFC Mission Assurance Requirements (MAR), NASA Program Requirements (NPRs) and Goddard Project Requirements (GPRs). More information on compliance with these requirements can be found in the *GPM GVS Product Development Handbook*.

GPM Mission Level 2 requirements call for GVS operations to begin at least 6 months prior to launch of the GPM core satellite. To meet this goal, the GVS will conduct pre-operational testing of all its elements, nominally beginning 12 months prior to GPM Core satellite launch. The GVS will then continue operational testing up to GPM satellite launch, and will operate as designed for the full 3-year GPM Core mission lifetime and the 2-year Low-Inclination Orbit (LIO) mission lifetime. This argues for a relatively simple and flexible GVS design that can be operated in a fashion that is as automated as possible.

All necessary steps will be taken to secure rights to data products, reports, documentation and computer code that the GVS makes available for archive and distribution. The GVS will also document, archive, and distribute its data policies and procedures to ensure seamless and secure access to its data holdings. Files ingested into the GVS will be tested for validity of its data content. Similarly, files distributed by the GVS will be tested for valid data content.

During the GVS operational lifetime it is expected that the ground validation research community will make continuous improvements in instrumentation and methodology. Thus, an approach that allows critical new measurement components to be incorporated in the data stream is essential. The GPM GVS will therefore conduct configuration management of all internal systems and software, data holdings, and interfaces. The goal is to ensure GVS performance as new instrumentation and methodologies migrate from research GVS operations.

3. GVS Archive and Distribution Function

The GVS Archive and Distribution (A&D) capability maintains the integrity of its data holdings by providing secure and reliable storage of, and access to GVS data, products, documentation, and reports. It is also the site for archive of the computer code and any ancillary data used in GVS product generation. The A&D also provides the interface to the PPS for delivery of scheduling and ancillary data products required by the GVS.

At a minimum, the A&D maintains all archive data in the original form in which it was received, even if the data are re-formatted for GVS product generation. The A&D provides Internet-based search and order capabilities that allows all users access to all versions of its holdings. Similarly, products are distributed from the A&D via the Internet. An interface for A&D search and order provides user access to materials in the GVS archive.

The A&D provides a limited customer service for science PMM Science Team members. This service allows Science Team members contact A&D staff by phone or email with questions about data products and services, and a reply is generated by the A&D staff. This service will not be available to general users.

During its operations, the GVS A&D will generate performance metrics related to, for example, data quality checks, the data volume and number of products ingested and distributed, the numbers of searches and orders, customer service requests, and replies.

4. Field Campaign and Product Generation (FCPG) Function

As described in the *GPM GVS Science Implementation Plan*, GVS observations for statistical validation of GPM products will be made in a series of investigator-led field measurement campaigns, known as Extended Observation Periods (EOPs). Several EOPs are envisioned, each lasting approximately 18 months, with each EOP punctuated by one or more Intensive Observation Periods (IOPs). Each subsequent EOP will move from one climatic region to another, as determined by the GPM Project in consultation with members of the PMM Science Team and other representatives of the atmospheric community.

Figure 4-2 illustrates the concept of the FCPG operated as a series of EOPS and IOPs. Some complement of GVS instrumentation will be fielded during each EOP. Additional instrumentation will be fielded during IOPs including, for example, aircraft-based instruments. It is expected that the first EOPs and IOPs will be executed well before the launch of the GPM Core spacecraft. It is the goal of the GVS for all instruments to collect data continuously, except for instruments on aircraft and rawinsondes.

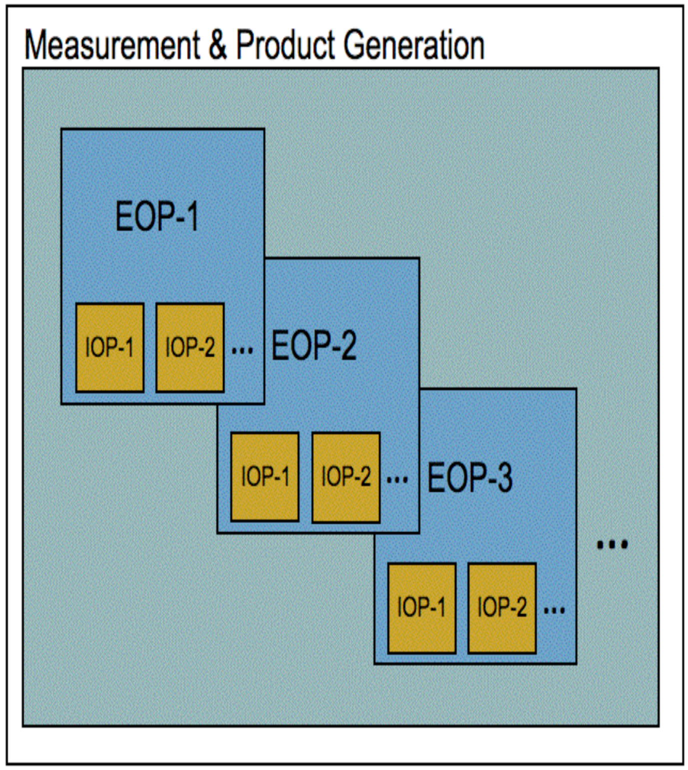

Figure 4-2. Illustration of the EOP and IOP concepts.

Data collection and local storage and archive will be internal to the GVS instrument systems. The data transfer component will be distributed between the instrument system and the centralized GVS A&D server. The detailed design of the data transfer means and methods will dictate the interface between the field systems and the central system, and will likely vary from one instrument system to another, and possibly from one site location to another. Specific Interface Control Documents (formal or informal) between the individual instrument systems and the GVS A&D system will be developed once the instrument systems are identified, developed, and acquired.

For instrumentation at existing ground validation sites, the data collection function typically will exist and be controlled by another organization. In these cases, only a data transfer function from the external ground validation system to the GPM GVS A&D function will be developed, and only if the data from the external ground validation system needs to be duplicated within the GPM GVS archive. Otherwise, the GVS will provide only a data link (e.g., as a url from the GVS web site) or availability information needed to obtain the data from the external ground validation system. The GPM GVS may maintain a catalog of available data from the external system in order to provide details on matching data sets for ground validation precipitation and coincident overpass events.

It is expected that data products from each instrument's Product Generation function will be provided to the GVS Archive and Distribution subsystem in data files in one of the well-defined hydrometeorological or data-sharing file formats. ASCII data will be in one of the encoded Hydrometeorological text formats [e.g., Standard Hydrological Exchange Format (SHEF), etc.], or an easily-parsed and convertible format, such as comma-separated values (CSV). Binary encoded data normally will be in either Binary Universal Format for Reports (BUFR) [for point observations such as rain gauges or rawinsonde] or Gridded Binary (GRIB) [for gridded products]. Post-processed data will be stored in GRIB, Network Common Data Format (netCDF), Hierarchical Data Format (HDF), or eXtensible Markup Language (XML). Scanning radar data will be in native NEXRAD Level II product format for S-band PPI data originating from WSR-88D radars. PPI data from the PI radars as well as other agency or university radars are expected to be provided in the Universal Format (UF), netCDF, or HDF file format. Where necessary, the GVS A&D function will decode and/or convert instrument data sets into netCDF, HDF, or XML.

4.1 Overall FCPG Operations

As mentioned above, EOPs and IOPs will be led by Principal Investigators (PIs). This approach to operations will hold true for investigator-provided instruments as well as for PI leadership of NASA-provided "facility instruments." Candidates for facility instruments include NASA's S-band dual polarimetric radar (N-POL) and the Ka-/Ku-band mobile, dual polarimetric radar that is under development by GPM GVS. Typically, instrument PIs will be competitively selected, with selection criteria matched to individual EOP requirements.

Figure 4-3 presents a schematic illustration of the organization and operation of PI instruments in EOP and IOP campaigns. Each GVS instrument will be managed by a PI who will be responsible for all aspects of their instrument's deployment and operations. All PIs will document the technical characteristics of the instruments, measurements, and data products. Such documentation is expected to take the form of an "Instrument Handbook" or equivalent. The Instrument Handbook will include information on the instrument point of contact; provide data descriptions (including data format) and examples; identify the primary variables measured, derived or retrieved; quantify the expected uncertainty of the measurements and retrievals; identify the method(s) for obtaining date and time stamps used in the file names and associated with individual measurements; identify the calibration and validation methods; describe data quality; and identify instrument metrics and reporting.

A file naming convention will be adopted for data provided by the FCPG instruments. The file name will indicate the nominal UTC date-time of the data in the file, the instrumentation and/or product type, and the instrument or network location ID. The instrument system needs no external information (orbit number, etc.) to generate a unique file name for the GVS. The GVS A&D function needs no information beyond the product file name to identify the type, nominal time, and site location of data in the file. Nominal time of the product data will vary by instrument and product. In the case of rain gauges or disdrometers, it may be the nearest hour for an aggregated hourly data file, as an example. For scanning radar, it could be the time of the volume scan (either the start, middle, or end time, by agreed convention). In all cases, product and file date/time information will be provided by a Network Time Protocol (NTP) server, or its equivalent.

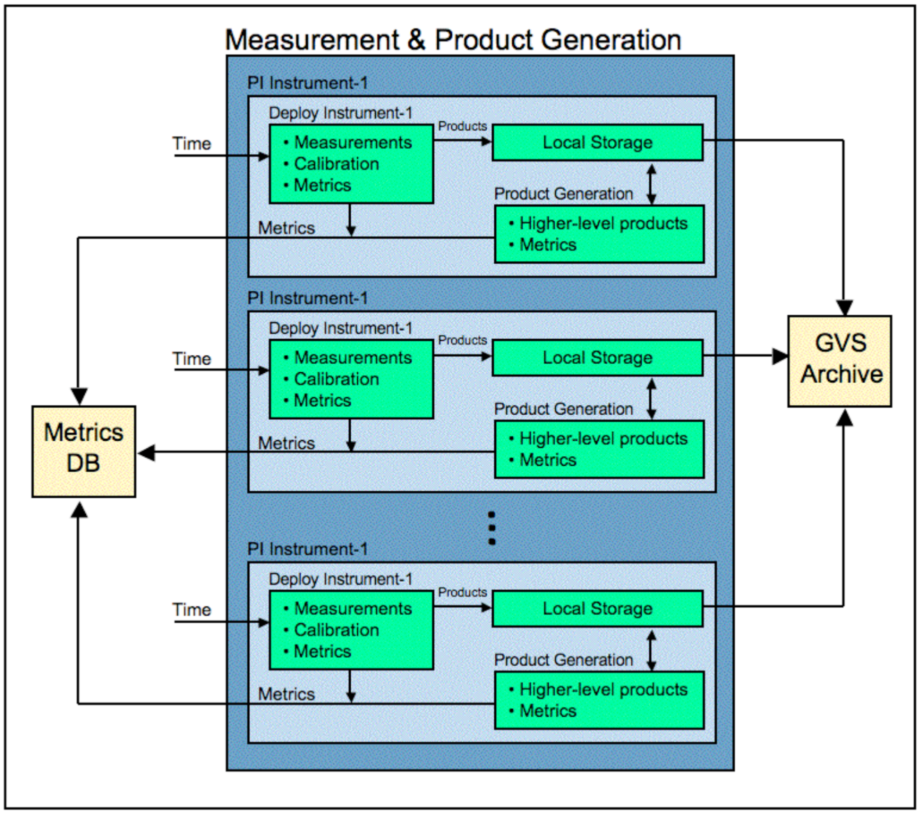

Figure 4-3. illustration of the Instrument Deployment and Product Generation functions during EOPs and IOPs.

Data from each instrument will be made available to the GVS A&D function via the most appropriate and cost-effective method. In most cases, this will be via secure file transfer over the internet in a push/pull configuration between the onsite data system for the instrument and the central GVS A&D system, as shown in Figure 4-3. In extreme cases such as network unavailability or low bandwidth with large data volumes or rates, data transfer will be by shipment of removable recording media containing a copy of the data. Data transfers internal to the overall instrument system (e.g., from individual rain gauges) will be the responsibility of the instrument PI. Where possible, existing data transfer and storage mechanisms such as those of the DOE Atmospheric Radiation Measurement (ARM) Climate Research Facility (ACRF) or the TRMM GVS will be leveraged directly or by duplication of the capability.

As shown schematically in Figure 4-3, each GVS instrument system will collect and archive data locally within the system (data collection), and provide data products to the GVS Archive and Distribution (A&D) function (data transfer). Where possible, data transfer from the instrument system to the A&D function on the central GVS server will be in real or near-real time over available communications networks, and will be automated. Both science data and instrument and instrument product status data and metrics will be sent to the A&D function from the instrument systems. Near-real-time ingest into the GVS A&D system of quick-look images from the X-band and S-band scanning radars and the S-band and UHF-band profilers, whichever is/are active in an active EOP/IOP study, is the minimum set of real-time data to be transferred. These data are necessary to facilitate remote control over operations of these radar systems by the PI or other GVS operational personnel.

4.2 FCPG Product Generation Operations

All PI-provided instruments create two types of data products: those comprising raw or lightly-processed instrument observations, and derived products which, depending on the data type, have been re-sampled in time or space, reformatted, quality-controlled, post-processed to derive additional parameters, and/or created from two or more parent data sets. In all cases, each PI instrument stores its results in a storage location that is specific and local to the instrument system and under control of the instrument PI.

Each GVS instrument executes the Product Generation function (see Figure 4-3). Since each GVS instrument is under the control of a unique PI, each Product Generation function associated with a given instrument will have a number of unique characteristics. The unique characteristics of the Product Generation function are described for each instrument, below.

One common characteristic of any data products is the Cartesian grid that will be defined specifically for product generation functions that generate the spatially re-sampled scanning radar products. The common Cartesian grid allows for routine inter-comparison of these and other GVS data products. Each 3-dimensional grid is constructed so that the scanning radar is located at the grid center and the grid extends in the x (east-west) and y (north-south), and z (vertical) directions. The resolution of the grid in all directions is uniform for each radar, with the resolution not exceeding the actual radar beam resolution at maximum horizontal range.

X-band re-sampled products. A dual-polarization X-band radar will generate resampled products include a reflectivity factor product (rZ_h and rZ_v in dB). An X-band re-sampled differential reflectivity factor product (rZ_{dr} in dB) will also be generated. Finally, an X-band scanning radar specific differential phase product (K_{dp}) will be generated from a polar coordinate product. The polar coordinate K_{dp} product will be resampled to the common Cartesian grid for all measurements in the entire scan volume where reliable differential propagation phase measurements can be obtained.

Although the production of 3-dimensional grids of radar data fields is specified as a derived product requirement of the X-band and S-band radars, it is more likely to be implemented as a function of the central GVS radar data post-processing. It makes sense to produce the 3-dimensional grids only after the radar data has undergone quality control and review.

Additional X-band radar derived product parameters include hydrometeor type, median drop diameter and number concentration, and rain rate.

S-band and Ka/Ku-band re-sampled products. In a similar fashion to the X-band products described above, several S-band and Ka/Ku-band products will be resampled and interpolated to a common Cartesian grid, but at a coarser (S-band) or finer (Ka/Ku-band) grid resolution as a result of the larger (smaller) area of coverage for the S-band (Ka/Ku-band) grids. The set of S-band and Ka/Ku-band scanning radar products to be resampled is identical to the X-band's in type and in the types and in the goals for the accuracies of the products generated.

S-band and UHF-band profiler products. The purpose of the S-band and UHF-band profilers is twofold: to provide reliable estimates of drop size distribution (DSD) parameters, and to provide a means for calibration and validation of the scanning radar estimates of precipitation. The S-band profiler is relatively sensitive to hydrometerors through the properties of Mie and Rayleigh scattering off of these hard targets. In contrast, radars at the longer UHF frequencies are sensitive to vertical air motion through scattering off of refractivity turbulence (Bragg scattering). In principle, the profiler Doppler spectra (containing the combination of Bragg and Rayleigh/Mie scattering components) can be used to retrieve the DSD. The retrieval of DSD is very sensitive to vertical air motion because DSDs uncorrected for air motion shift the spectra toward larger drops in downdrafts and smaller drops in updrafts. The use of two profilers operating in two frequencies enables air motion to be estimated with one profiler and the precipitation motion to be estimated with the other under a variety of meteorological conditions, thus providing a better estimate of DSD than with either instument operating alone.

The S-band and UHF-band profiler will operate as a pair and sample a common volume of the atmosphere to produce vertical profiles of mean reflectivity, mean reflectivity-weighted Doppler velocity, and velocity variance at each range gate. Derived product parameters will include vertical air motion, mean cloud/precipitation particle diameter and concentration, raindrop Gamma shape parameter, and raindrop size distribution.

Disdrometer and rain gauge products. Rain gauges remain the standard by which all other precipitation measurements and estimates are evaluated, and a precipitation gauge network will be a major component of the GVS instrumentation suite. GVS rain gauges will have a 1-minute sampling capability to estimate instantaneous rain rates, and will generate precipitation rate and precipitation accumulation products over 1-minute, 5-minute, and 1-hour intervals. Gauges will be deployed singly, to maximize areal coverage, or in pairs, to maximize quality and accuracy of the measurements. For GVS sites where validation of DPR and ground radar reflectivity and derived rain rates are a primary goal, paired gauges will be deployed in a dense cluster to try to capture the within-pixel or within-bin variability of precipitation. For GVS sites where the areal-average or integrated rainfall amount is required, rain gauges will be deployed evenly over the study area (e.g., the river or stream basin). Gauges will be either NASA-owned, owned by another agency, or a mix of the two, depending on the GVS site.

Disdrometers will measure drop size distribution (DSD) and derived rain rate and reflectivity at a fixed point on the ground surface. They will provide the only direct measurement of DSD except in the rare events when instrumented aircraft are operating. DSD is a critical measurement affecting the accuracy and validity of all remotely-sensed rain estimates. Disdrometers will be deployed in a similar manner to, and co-located with, the rain gauges, although they will be many fewer in number. A disdrometer will also be co-located with the S-band and UHF profilers to provide DSD surface coverage and ground truth for these instruments.

Profiling microwave radiometer products. The GVS profiling microwave radiometer will provide vertical profiles of temperature and water vapor from the ground level to 10 km above ground level at 15-minute or smaller time intervals above a fixed-point location. It is expected to be able to operate continuously and have a rain mitigation capability to operate in active precipitation. These products help to interpolate the vertical state of the atmosphere in between rawinsonde launch times.

Rawinsonde products. The basic GVS rawinsonde product consists of vertical soundings of wind speed (ms^{-1}), wind direction (degrees), temperature (K), pressure (mb), relative humidity (percent), and altitude (m) in ≤2-second-intervals, beginning at the surface and extending to at least 100 mb. The GPM GVS rawinsonde system will have Global Positioning Satellite (GPS) tracking capabilities. The basic sounding products will be interpolated to regular pressure levels for use in model initialization. Rawinsonde soundings will be taken only during selected precipitation events in an IOP or an EOP.

4.3 Site Selection and Instrument Deployment

A key lesson learned from the Tropical Rainfall Measurement Mission (TRMM) is that errors in precipitation data products are not universal, but have a strong dependence on meteorological regimes. As such, the GPM Ground Measurements Advisory Panel recommended that GPM should direct its GVS measurements to selected meteorological regimes, particularly those where there are large errors or large uncertainties in retrieval of precipitation estimates from satellite observations. Consequently, the FCPG will be executed as a series of deployments to different regimes throughout the mission lifetime. The advisory panel also recommended that GPM validation activities consider not only the satellite products, but also the merged precipitation products based on cloud resolving models and coupled land surface/cloud resolving models used in hydrologic applications. Therefore, field measurement campaigns will be designed to address both model and satellite validation objectives.

The location and duration of GVS field measurements will be made as a series of adaptive decisions prior to and during the GPM mission. The Precipitation Measurement Missions (PMM) Science Team and the GPM Ground Measurements Advisory Panel will play a role in making decisions about the scientific focus and location of each deployment. Final decisions on deployments will be the responsibility of GPM Project management. These deployments can be defined in terms of Extended Observation Periods (EOPs) and Intensive Observation Periods (IOPs).

5. Validation Network (VN) Function

The GVS VN operations concept describes the data, systems, processing, and phased development involved in the implementation of VN requirements. The VN requirements for GPM at the most basic level are to compare calibrated, attenuation-corrected reflectivity from the Tropical Rainfall Measurement Mission (TRMM) Precipitation Radar (PR) and the GPM Dual-Frequency Precipitation Radar (DPR) to space- and time-coincident ground-based radar reflectivity, primarily from the Weather Surveillance Radar-1988 Doppler (WSR-88D, or "NEXRAD"), over the Continental United States (CONUS). The aims of the reflectivity comparisons are to:

- Evaluate the effectiveness of the PR/DPR attenuation correction algorithms in various precipitation situations by comparison to unattenuated ground radar reflectivity at low altitudes and/or in heavy precipitation;
- Evaluate the accuracy of the WSR-88D reflectivity calibrations at each ground site by comparison to the well-calibrated PR/DPR reflectivity with precipitation echoes at higher altitudes or in situations where PR/DPR attenuation at lower altitudes is minimal.
- Provide a data set that can be used for assessing GPM data product algorithm accuracy in various precipitation regimes.

The methodologies envisioned for the VN reflectivity comparisons derive in large measure from published investigations of TRMM PR reflectivity to ground-based radar reflectivity. The VN will extend these methods to the full national network of WSR-88D radars in a near-real-time, semi-automated environment. For details, refer to the GPM GVS Level 3 Requirements.

5.1 VN System Description

Figure 5-1 presents a schematic overview of the functions and processes involved in the GPM GVS VN. The data ingest function acquires WSR-88D Level II products and GPM Precipitation Processing System (PPS) Site Overpass and Level 1 and 2 data products from GVS-external systems. The Data Pre-processing function is shown in green in the figure. The Data Post-processing and Analysis function is in orange, the Interactive and Scheduling function is in pink, and the Manual Quality Control function is in blue. Each of these functional areas is described in the sections below.

The GVS VN will operate subject to the overall GPM GVS functional, operational, archive, and performance requirements, which are described elsewhere in this document and in the Global Precipitation Mission (GPM) Ground Validation System Level 3 Requirements.

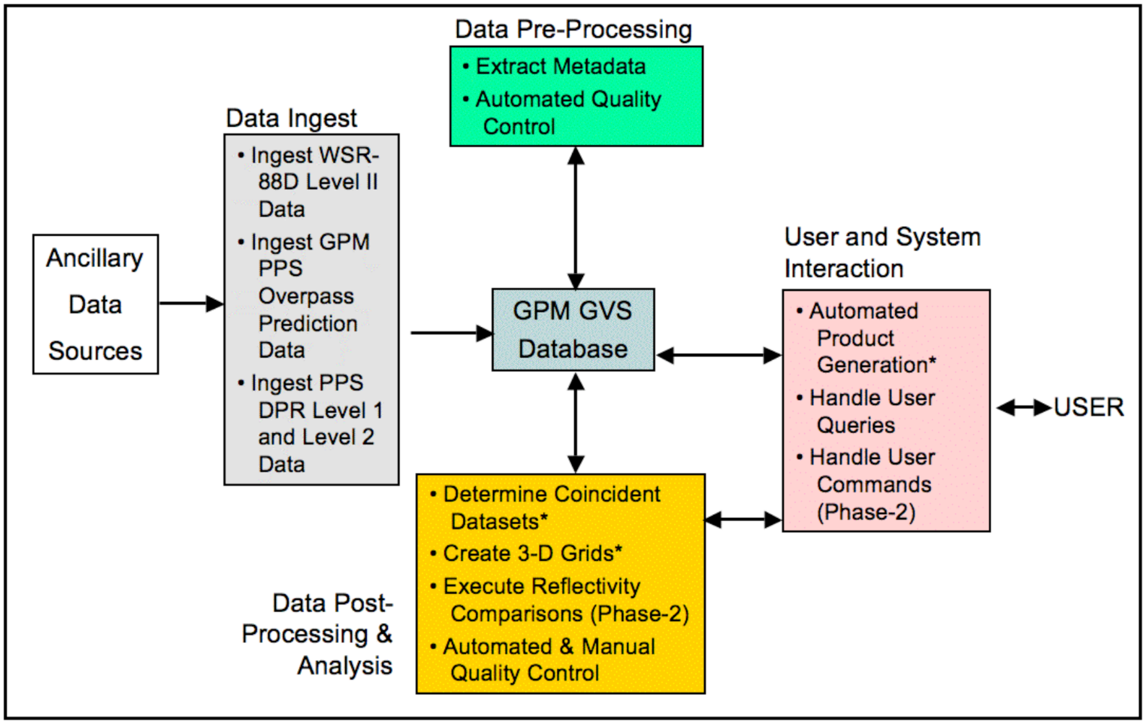

Figure 5-1. Overview of major functions and processes of the GPM GVS VN. Processes that have expanded Phase-2 capabilities are noted with an asterisk (*).

5.2 Data Ingest Sub-Function

The data ingest processes of Fig. 5-1 are general components of the GPM GVS, with VN enhancements to acquire these specific data over the entire CONUS rather than just at a few GPM GVS EOP and IOP sites. Only those data components of the GPM GVS pertinent to the VN are described here.

The Ingest WSR-88D Level II Data process will acquire data from the national network in near-real-time from the Internet-II data source using the Local Data Manager (LDM) software package, or their equivalents in the GPM mission time frame. This mechanism is currently used in a TRMM GVS prototype system to acquire WSR-88D data for a limited number of ground radar sites. GVS operations will expand this prototype to include data acquisition for all WSR-88D sites in the CONUS, and the system may be expanded to include additional, international radar sites.

During the GPM era, the Ingest GPM PPS Overpass Prediction Data process and the Ingest PPS DPR Level 1 and Level 2 Data process will interface with the PPS to acquire overpass data products. Prior to the GPM launch, the GVS will acquire comparable products for TRMM via the existing TRMM PPS interface. The PPS will provide the necessary products to the GVS from a ftp server. During VN operations the PPS will provide PR/DPR overflight data corresponding to every WSR-88D in the CONUS. Once acquired, the VN Data Ingest Function will conduct basic format checking on the ingested products and pass them to the GPM GVS database as illustrated in Figure 5-1.

5.3 Data Preprocessing Sub-Function

The Data Pre-processing function extracts metadata from the WSR-88D Level II and GPM DPR data products, and executes automated quality control (QC) procedures on the WSR-88D reflectivity data. These processes are shown in the light green box in Fig. 5-1.

The Automated Quality Control process applies automated QC algorithms to all the data and stores the associated QC results in the GVS database.

The Extract Metadata process harvests additional metadata from the WSR-88D and PR/DPR products. Such metadata will be used to help users identify and work with specific sets of GVS data. For example, extraction of pertinent precipitation state metadata and its linkage to data products in the database will allow a rapid determination of whether one, both, or neither of the coincident ground and satellite radar data for an overpass indicate the presence of precipitation echoes. Data for precipitation events and non-precipitating events could then be stored in separate databases, e.g. offline for non-precipitating events, and online for precipitating events. A more complicated user search and data selection scenario might be to identify and fulfill a user request for the subset of data where both the ground and space radar indicate stratiform precipitation covering over 50% of the overlap area between the two radars, the ground/satellite radar overlap area itself is 75% or more of the VN 3-D grid volume centered on the ground radar, and the location of the bright band is less than or equal to 3 km above ground level (AGL). This latter scenario will require additional metadata to be produced and stored in the database as the ingested products are processed within the GVS (see following section).

Useful metadata elements to be extracted or calculated from the WSR-88D Level II data potentially include:

- Nominal volume scan time, e.g. begin time of the volume scan
- Volume Coverage Pattern (VCP) ID number – defines elevations present in the volume, sampling mode, and time to complete the volume scan
- Begin time and elevation of each elevation sweep
- System gain calibration constant
- Percent of range bins above a reflectivity threshold for precipitation
- Results of automated QC algorithms
- Data quality and availability metrics for the GVS Metrics Database.

The VN reads and quality controls PR/DPR data, and extracts metadata. Useful metadata elements to be extracted or calculated from the GPM PPS PR/DPR Level 1 and 2 data products potentially include:

- Datetime and nadir-to-site distance of nearest approach to, and location ID of each ground radar overpassed in a given orbit number
- DPR Level 1 and 2 data granule(s) or product identifier(s) included within the overlap area for each location overpass event described by the previous bullet
- A flag indicating actual or empty data for each data element of the preceding bullet

- Geolocation accuracy estimates for each DPR overpass data product
- A flag indicating whether or not precipitation is indicated in the DPR overpass data product
- Flags indicating the conditional type(s) of precipitation characterizations indicated in each DPR overpass data product (Level 2 -- can link back to matching Level 1 product); e.g., convective, stratiform
- For each ground radar location overpass event, percentage of each "standard" 3-D grid volume covered by:
  - Ku-band PR
  - Ka-band PR
- Average height (AGL) of the bright band within the overlap area as detected by the PPS DPR Level 2 algorithm
- Algorithm version number for each original and reprocessed PPS data product provided
- Data quality and availability metrics for the GVS Metrics Database

A GPM GVS data model accounting for the available and desired metadata for the various GVS data will support the types of data queries and processing envisioned by the GPM science team. The GVS database will support the users' needs as defined by the GVS data model, and system requirements. In the context of the VN Operations Concept, the GVS database of Figure 5-1 includes both the science data for the VN, and the GVS Metrics database described in the GPM GVS Level 3 Requirements.

5.4 Data Post-Processing and Analysis Sub-Function

The Data Post-Processing and Analysis sub-function includes three high-level processes: Determine Coincident Datasets, Create 3-D Grids, and Execute Reflectivity Comparisons. The Determine Coincident Datasets and Create 3-D Grids processes will be part of the Phase-1 or initial core functionality of the VN system. The Execute Reflectivity Comparisons process will be implemented as a Phase-2 capability. In Phase-1, The Determine Coincident Datasets and Create 3-D Grids processes are executed automatically under system control. In Phase-2, these processes may be initiated either under system control (routine, default) or user control (non-routine).

5.4.1 Determine Coincident Datasets Process

For VN Phase-1 operations, and in routine, scheduled operations during Phase-2, the Determine Coincident Datasets process will use a set of default area-of-coverage overlap and time offset rules to match up PR/DPR products to WSR-88D products, at the granularity of a given overpass of an individual ground radar site. Information linking the matching products will be stored in the GVS database to allow easy identification, retrieval, and processing of the paired data. In essence, the Coincident Dataset is simply a set of links between products stored in the GVS database, for a given set of matchup rules. The links may exist as tables in a relational database or in a set of tabular files, depending on how the GVS is implemented. It does not require the duplication or prepackaging of the radar data themselves. The Determine Coincident Datasets process for the default case will be automated and triggered either by the receipt of necessary input data or at fixed times (e.g., by the crontab).

VN Phase-2 will permit non-routine operations such as a user-initiated operation. For example, in Phase-2 operations of the VN the Determine Coincident Datasets process will permit users to specify custom parameters that define the areal overlap and time offset thresholds to be applied to determine the matching satellite and ground radar products. Other parameters, such as the time period (begin and end dates), precipitation regime, or region of the U.S. may be specified to bound the data for which custom, coincident data sets are determined in the non-routine case. These custom match-ups may be stored in the GVS database separate from the default match-ups. Only authorized users will have the permissions necessary to define, create, and store custom matchup datasets during Phase-2 operations of the VN.

In either operating mode, depending on how the satellite and ground radar data are broken out in time and space, there may be up to two each of the satellite and radar granules/products in the matchup, though the norm will be a one-to-one match. For instance, if a DPR overpass of a WSR-88D occurs exactly between volume scans of the ground radar, the higher-elevation sweeps of the preceding volume scan and the lower-elevation sweeps of the succeeding volume scan will be the best match in time to the DPR data, as the WSR-88D volume scan strategies are one-way, from low to high elevations.

5.4.2 Create 3-D Grids Process

The Create 3-D Grids process is a Phase-1 capability that conducts coordinate transformation and interpolation to map the polar-coordinate, fixed-elevation-angle, ground radar data and the line-scan, height-AGL-binned, satellite radar data to common three-dimensional grid volumes. This process will be based on the methods currently used in the TRMM GV processing of PR data and ground radar data for specific TRMM GV locations (see http://trmm-fc.gsfc.nasa.gov/trmm_gv/), enhanced to include GPM DPR data, coverage over the national network of WSR-88D ground radars, and VN metadata extraction and storage. The details of the specific transformation algorithm to be used will not be presented here. An initial capability is currently in place for the prototype VN. The transformation algorithm used in the prototype VN is expected to change over time in response to recommendations from the PMM Science Team.

A single pair of 3-D reflectivity grids, one of satellite-based data and one of ground-based data, will be routinely produced by the Create 3-D Grids process for each PR or DPR overpass of a WSR-88D national network site in the CONUS, when the overpass meets the default criteria for overlap of the satellite and ground based radar areas of coverage, i.e., when they are determined to be coincident. The Create 3-D Grids process for the routine, default case will be automated and triggered either by the availability of necessary input data (i.e., as each coincident dataset is identified by Determine Coincident Datasets) or at fixed times (e.g., by the crontab). The resulting 3-D grids will be stored in the GVS database along with links to the coincident dataset from which they were produced.

In VN Phase-2, non-routine capabilities such as a user-initiated operation will be possible. In this phase of operations the Create 3-D Grids process will accept custom parameters to define the underlying map projection, gridpoint spacing and dimensions for the 3-D grid. Other parameters, such as the time period (begin and end dates), precipitation regime, region of the U.S., and the matchup dataset to be used to determine the matching satellite and ground radar products may be specified to bound the data for which custom, 3-D grid sets are generated in the non-routine case. Only authorized users will have the permissions necessary to define and create custom 3-D grid datasets within the GVS during Phase-2 operations of the VN.

In all phases of VN operations, the Create 3-D Grids process will include ancillary functions to analyze some basic characteristics of data in the 3-D grids and produce descriptive metadata based on these analyses. The metadata elements so produced will be stored in the GVS database with links to the related 3-D grids, and by association, to the matchup radar products from which the 3-D grids are produced. Storage retention of the metadata elements in the database will match those of the 3-D grids from which they were derived. The types of metadata to be derived from the data in the 3-D grids may include:

- Percentage of the horizontal grid area within which precipitation is present, based on a reflectivity threshold, for each vertical level in the 3-D grid
- Percentage of the 3-D grid in which overlapping PR or DPR data are available (partial overlap coverage will be allowed and is likely to be the norm)
- Maximum and minimum vertical grid levels where the bright band occurs within the 3-D grid
- Percent missing data in each level of the 3-D grid
- Type(s) of precipitation (convective, stratiform, etc.) present in the 3-D grid (this in itself may be a 2-D array indicating the dominant precipitation type in each vertical column of the 3-D grid)

3-D grids may not be produced, and will not be stored, for the “null case” where no precipitation echoes are present in either the PR/DPR or ground radar data, or where one or both of the satellite and ground radar data sets are missing or flagged as bad by QC. In the null case, only a metadata flag will be stored to indicate the condition responsible for the null case. Other than basic error checking of the input data, the Create 3-D Grids process will not perform any quality control on the output grid data. However, QC flags will be associated with each 3-D grid stored in the database, with values initialized to “no QC performed”. In VN Phase-2, these values can be reset by analysis and processing of the Execute Reflectivity Comparisons process, or manually.

The resolution of the default 3-D grids in the horizontal should not be finer than the largest dimension of the satellite or ground radar data samples within the grid domain. For the WSR-88D and a nominal grid domain of ±100 km from the radar, the driving resolution is the PR or DPR instantaneous field of view (IFOV) of approximately 5 km, and so this will be the default resolution of the 3-D grids. The WSR-88D resolution within this domain is 2.5 km or better, which would result in subsampling of the PR/DPR data and increased data storage and transmittal requirements.

Note: If satellite-to-radar grid co-registration, warping. morphing, etc. are implemented as a supported algorithm in the Execute Reflectivity Comparisons process, then a much smaller horizontal grid domain (±25 km) and gridpoint spacing (0.5 km) may be used for the common 3-D grid, or a second set of 3-D grids at this higher resolution may be produced.

5.4.3 Execute Reflectivity Comparisons Process (Phase-2)

The Phase-2 GPM GVS VN will include an Execute Reflectivity Comparisons process to produce statistical summaries and graphs of the results of ground-to-satellite reflectivity comparisons derived from the 3-D grids. Examples of products to be created possibly include, but are not limited to:

- Scatter plots of satellite vs. ground radar reflectivity (Figure 5-2)
- Time series of mean monthly bias of WSR-88D reflectivity relative to PR/DPR (Figure 5-3)
- Plot of mean ground-satellite reflectivity difference vs. PR/DPR reflectivity category (Figure 5-4)
- Vertical profile of mean ground-satellite reflectivity difference (Figure 5-5).

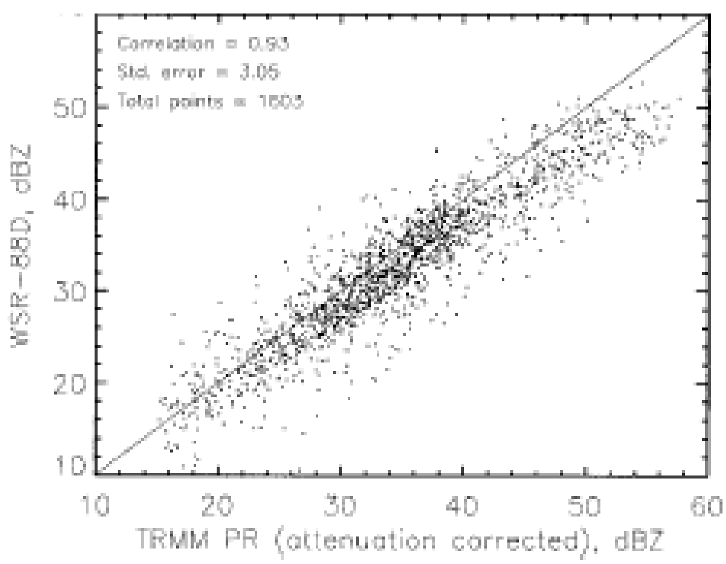

Figure 5-2. Example scatterplot of WSR-88D vs. TRMM PR attenuation-corrected reflectivity. From Liao, et al. (2001).

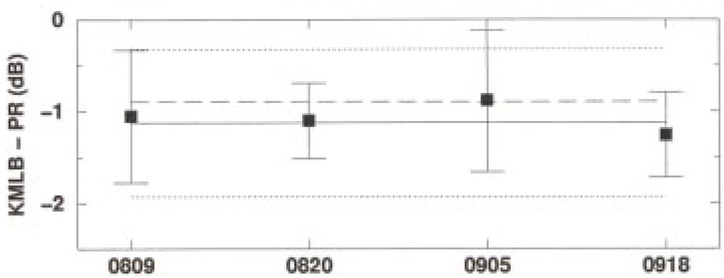

Figure 5-3. Example time series of WSR-88D – TRMM PR attenuation-corrected reflectivity. From Anagnostou et al. (2001).

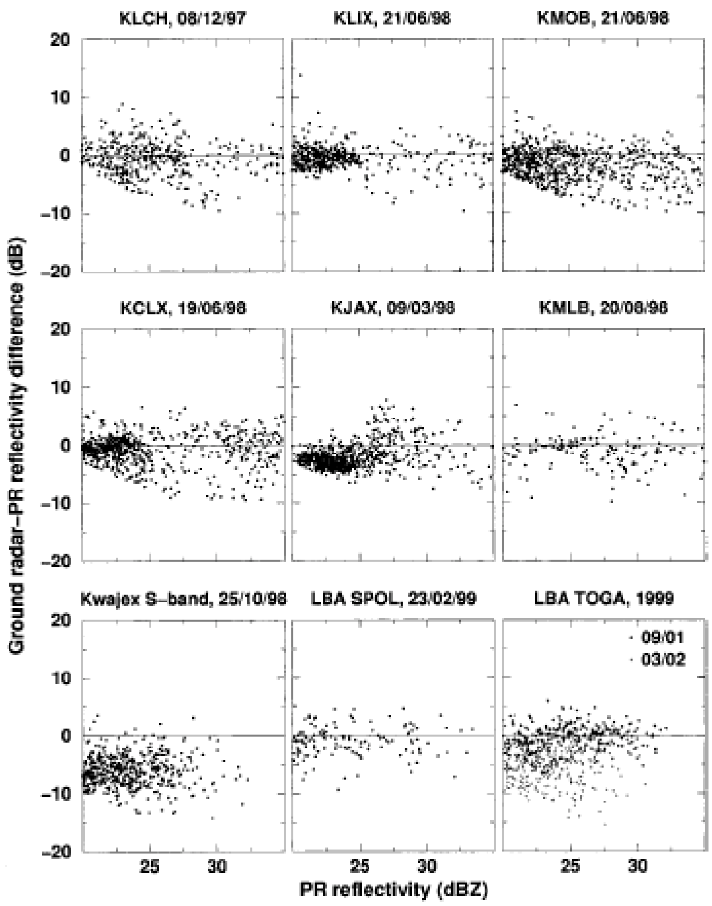

Figure 5-4. Example of WSR-88D –TRMM PR attenuation-corrected reflectivity difference vs. PR reflectivity category. From Anagnostou et al. (2001).

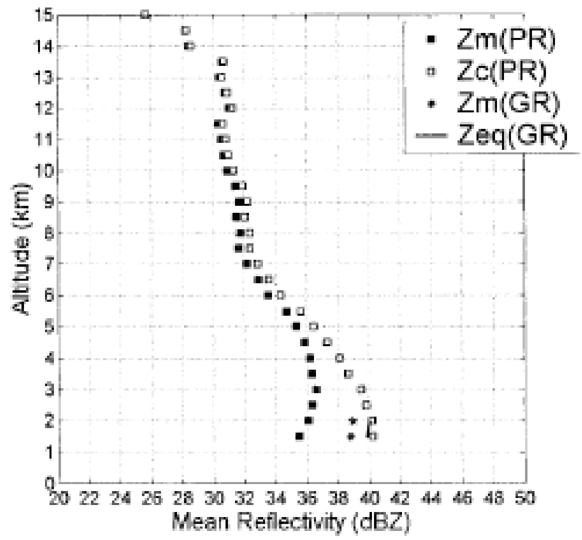

Figure 5-2. Example vertical profiles of WSR-88D and TRMM PR reflectivites. From Bolen and Chandra (2000).

The Phase-2 VN will produce a default set of reflectivity comparison products on a scheduled basis. The default products will be for individual WSR-88D locations over a statistically meaningful time period (monthly or longer). If feasible, an attempt will be made to produce default products specific to precipitation regime (convective, stratiform, light rain, snow, etc.), elevation (above bright band; below bright band), or other predefined situations by applying metadata rules limiting the input 3-D grid data to those meeting the desired criteria.

The Phase-2 Execute Reflectivity Comparisons process will perform quality control on the reflectivity comparisons to determine, as best as possible, whether there are significant geolocation errors (for PR/DPR reflectivity) or anomalous echoes (anomalous propagation, ground clutter, etc.) from the ground radar. Where possible errors exceed defined thresholds, the affected 3-D grids will be flagged in the database and excluded from the product results. A summary (Datetime, data type, QC check failed) of excluded grid data will be produced for the default output product and stored in the database as metadata associated with the product. The output display products will indicate, at a minimum, the number of grid pairs excluded from the results due to failure of QC checks.

In Phase-2, an option will be provided to manually override the individual 3-D grid QC flags which result from the automated reflectivity comparison QC checks from a prior product generation run. In the case where the manual override value indicates to force inclusion of 3-D grid data otherwise flagged for rejection by the QC, the output display product may be regenerated with the flagged data included in the results.

The Phase-2 default products of the Execute Reflectivity Comparisons process will be stored in the GVS. The GVS will provide an online catalog of reflectivity comparison display products, from which products may be selected, viewed, and downloaded. These products will be publicly available online.

Authorized users will have the capability to specify the parameters and criteria used to produce reflectivity comparisons supported by the capability to created customized comparison displays. These users will be able to use either default- or custom-produced 3-D reflectivity grids as input to the reflectivity comparison display generation.

The Manual Quality Control process is executed during both Phases of the VN, but only in cases where it is determined from coincident WSR-88D and satellite data that a rainfall event has occurred. Analysis has shown that the probability of a rainfall event over a WSR-88D site coinciding with a GPM DPR overpass occurs on the order of about 2 times per month per site. When a joint event such as this occurs, the GVS will conduct a manual review and QC of the WSR-88D reflectivity data. Following the QC step, the GVS will either store a modified version of the reflectivity product and applied QC results to the database, or the GVS will flag the data as good (use as-is) or bad (data rejected), depending on the nature and location of the data problems within the product. The original, unmodified WSR-88D data will be retained in either case.

5.5 Scheduled and Interactive Tasks Sub-Function

In Phase-1 of VN operations, users will be able to search coincident PR/DPR and NEXRAD radar reflectivity data (both raw data and data resampled to a common grid) using search criteria for metadata attributes such as those defined in Section 5.2. Users will also be able select data from search results for download via the online access capabilities of the GPM GVS.

Routine data ingest and storage, pre- and post-processing, and generation of the common grid product will be fully automated for Phase-1 operations. Depending on the child process, initiation of the Automated Product Generation process will be either triggered by receipt of necessary input data or scheduled by the system. A default set of parameters to define coincidence of data sets, generation of 3-D grid volumes, time periods covered in the output display products, and stratification of the data contained in the output products will be defined. The default parameters will be retrieved and applied in the routine processing of the VN data.

Phase-2 routine operations will have all the capabilities of Phase-1. In addition, users will be able to select pre-generated products for display or download from the online access to the GPM GVS. This is indicated by the Handle Data Queries process shown in Figure 5-1. This capability will follow the general data accessibility and interactivity requirements for the overall GPM GVS.

The Phase-2 Handle User Commands process illustrated in Figure 5-1 will provide interactive capabilities for authorized users to specify different sets of parameter values to control the operation of various other processes that create customized, non-routine products on demand. It will also provide the interfaces to run QC procedures and manually modify QC flags in the database to override the results of the built-in QC functions.

The Automated Product Generation process shown in Figure 5-1 is the parent process which controls the child processes to determine coincident data sets, and to create the 3-D reflectivity grids. In Phase-2, the capabilities of this process will be expanded to generate the reflectivity comparison display products during routine operations.

5.6 VN Performance

The primary performance criterion for the VN is to avoid a "data backlog" in ingest, processing and product delivery. As such, the VN will generate raw and gridded products within 24 hours of receipt of required input data, so that the daily queue of acquired products is cleared on a daily basis. to achieve this goal, all VN processes except QC will be fully automated, and the QC processes will be automated to the fullest extent possible.

In addition to providing automated, on-line access to data, the VN will also provide a limited "user services" capability for responding to PMM Science Team requests for non-standard products. In this case, non-standard products include those products that are not routinely produced, stored, or otherwise available in the online catalog. The VN will respond to PMM Science Team inquiries about non-standard products within two (2) working days of the request. It is the goal of the VN to fulfill PMM user requests for non-standard products within three (3) working days it if no re-coding is required. Requests for non-standard products from users other than PMM Science Team members will also be acknowledged within 2 working days, and the requests will be reviewed by the PMM Project Scientist (or designee) for completion on an "as resources are available" basis.

6. GVS Metrics Database Function

The Metrics Database (MD) is a tool for management of the heterogeneous and distributed elements of the GVS. As described above, the FCPG, A&D and SSM elements of the GVS all generate performance and process metrics, and these metrics are delivered to the MD for safe and reliable storage. The MD allows GPM management to evaluate the performance of the GVS VN and FCPG functions.

7. GVS Interfaces

The GPM GVS has a number of interfaces with external elements as described briefly in Section 2, and as illustrated in Figure 2-2. These interfaces are described in greater detail below.

7.1 Precipitation Measuring Mission Science Team

The Precipitation Measuring Mission (PMM) Science Team interacts with all aspects of the GPM GVS. First, in terms of instrumentation and measurement, the PMM Science Team identifies requirements for an initial set of ground-based instrumentation and for the algorithms needed to retrieve atmospheric parameters from the ground-based measurements. Members of the science team also assist with validation site selection, as well as the selection, delivery, and operations of GVS instrumentation. The PMM Science Team provides algorithms that drive the validation and model-based analysis, which forms the basis of the GVS physical validation. The measurement and validation/modeling components of the GVS generate data products that are stored in the GVS, and the PMM Science Team interacts with the archive and distribution capabilities of the GVS as needed to acquire GVS data products. Team members may also search for and receive current and historical versions of data products stored within the GVS. Team members with questions about GVS data and services can send email to a GVS customer service representative and subsequently receive an email reply. Over time, members of the PMM Science Team will make recommendations to the GVS on infusion of new instrument technologies for field campaigns, new ground validation retrieval algorithms, and new validation procedures.

7.2 Precipitation Processing System

The Precipitation Processing System (PPS) provides predictive and actual overflight schedules to the GVS. This scheduling information enables GVS ground sites to coordinate instrument and measurement operations with the GPM core and constellation spacecraft. Analysis has shown that the probability of a precipitation event occurring during a core satellite overflight of a given ground site is on the order of about 2 times per month. Thus, capturing precipitation events during overflights is an important target-of-opportunity for GPM GVS operations. The PPS also delivers GPM core spacecraft data to the GVS that are processed to Level 1 and Level 2. These satellite data products will be used in the VN.

7.3 General Users

A world-wide community of users may access GPM GVS data products via the archive and distribution capabilities of the GVS. Users can query and search the historical archive of GVS data products and request data delivery via the Internet.

7.4 GPM Management

During operations the GVS routinely generates metrics on ground-based instrument performance, validation and characterization processes, product generation, and on the performance of the VN and GVS archive/distribution. These metrics are recorded, stored, and used by GPM management to evaluate the performance of the GVS VN and FCPG functions.

7.5 Ancillary Data

The VN element of the GVS acquires ancillary data from NOAA's Weather Surveillance Radar-1988 Doppler (WSR-88D, or "NEXRAD") collected at ground stations throughout the continental United States. See Section 5 for additional details on this interface.

7.6 Long-Term Archive

At the end of the operational life-time of the GPM Core Satellite the GVS will prepare a copy of all current versions of its data products and product generation software for delivery to a non-GPM long term archive.

8. Mobile Ka-/Ku-band Radar

A dual-frequency, dual-polarization, Ka-/Ku-band meteorological research radar will be operated as part of the GPM GVS. The choice of the Ka (0.75 – 1.2 cm, 27 – 40 GHz) and Ku (1.7 – 2.5 cm, 12 – 18 GHz) bands was made for two reasons. Firstly, the GPM satellite's Dual-frequency Precipitation Radar (DPR) instrument operates at these frequencies. Secondly, while there are a number of research radars operating at S, C, X, and Ka bands, there is only a single research radar operating both the Ka and Ku bands on a single mobile platform. This radar, the Advanced Multi-Frequency Radar (AMFR) developed by the University of Massachusetts has only seen limited operations, and was developed using magnetron power amplifiers. The Ka/Ku-band radar developed for GPM GVS will be based on solid-state amplifier technology.

8.1 Electrical Performance

As mentioned above, the Ground Validation System Mobile Radar (GVSMR) will operate in the Ka and Ku bands, and the radar will have a beam width of 1-degree or less (measured as full width, half power) in each frequency range. The radar will transmit and receive in both horizontal and vertical polarizations in each band, with the H and V patterns matched to within 5 dB, integrated over the main lobe of the antenna pattern. The radar's Ka and Ku bands will each have a maximum sidelobe gain of -25 dB compared to the main lobe of the antenna pattern. Both bands will have a cross-polarization isolation of 32 dB to ensure its ability to detect mixed-phase precipitation. For both Ka and Ku bands, the radar will have a minimum detectable signal of -10 dBZ at 15 km in clear air for a single pulse measured with 150 km range resolution. This level of sensitivity is greater than that on the GPM DPR. It is expected that the radar can be used to both validate the DPR algorithms and to study atmospheric phenomena of interest to the research community, for example, to observe the formation of precipitation in clouds.

It is essential for both the Ka and Ku channels of the radar to view the same volume of the atmosphere, and to do so as accurately as possible. Therefore, the radar is designed so that the Ka and Ku bands are co-aligned to within one-tenth of the 3 dB beam width. The radar receiver isolation exceeds 35 dB between channels, and the dynamic range of both channels is quantized to 16 bits (although an initial version of the radar will have a signal quantization of 14 bits).

8.2 Physical/Mechanical Performance

The Ka/Ku radar will operate as a volumetric radar, capable of scanning in the azimuth and elevation directions to sample a full 3-dimensional volume of atmosphere. The radar will have a minimum range of 100 m and will sample with a minimum range resolution of 30 m out to the useful range of radar sensitivity. This range resolution will be selectable up to a range resolution of 270 m (i.e., pulse lengths of 0.2 _sec to1.8 _sec in 0.2 _sec steps). The radar will have an elevation pointing knowledge uncertainty of ≤0.2 degrees in the azimuth and elevation direction. It will be capable of scanning ≥4 degrees/sec in elevation and ≥36 degrees/sec in azimuth. The radar will have a elevation and azimuth pointing resolution of ≤0.1 degree, with an elevation look angle range of -0.5° to +90, and a full 360° range of azimuth scanning. These specifications allow the radar to be scan synchronized with any Weather Service WSR-88D unit. They also provide the radar with the scanning resolution needed to accurately point at calibration targets.

8.3 Instrument Product Generation

The Ka/Ku-band radar will generate the full suite of dual polarization and Doppler radar products listed in Table 8-1. These products will be generated in the native resolution of the radar (in polar coordinates) as well as products resampled to a uniform Cartesian grid. The radar will also be capable of collecting a full set of up to 2 hours of continuous time series data collection, when specified to do so by an operator.

Table 8-1. Radar Data Products

Parameter	Description	Unit	Accuracy goal
Z_h and Z_v	Equivalent radar reflectivity factor (h and v polarization)	dB	≤1.0 dB*
Z_{dr}	Differential reflectivity product	dB	≤2.0 dB*
_dp	Differential propagation phase	degrees	≤3.0°
_hv	Co-polar correlation coefficient	unitless	≤0.005
LDR	Linear depolarization ratio	dB	≤1.0 dB
	Doppler radial velocity	m/sec	± 1 m/sec

*independent of attenuation correction

8.4 General Instrument Characteristics

Given that the GVS will support field campaigns in various climatic regimes, the GVSMR radar has been designed to be a transportable, self-contained, truck-mounted system capable of traveling from one field site to another. The radar is designed to be able to perform full operations within 72 hours of delivery to a field site, and to be capable of transitioning from operations to a state ready for transport within 72 hours of notification. As part of the radar's capability to conduct self-contained operations in the field, the GVSMR can use commercial power sources (single or 3-phase, 100 V to 240 V, 50 Hz to 60 Hz), or the radar can run off of an on-board generator.

The radar is also capable of unattended operations. In the unattended mode, the radar had the capability to:

- be operated from a remote location via electronic networks, including the ability for a remote operator to modify and execute scan sequences

- distribute a selectable list of products in near-real-time over wired and wireless electronic networks
- operate autonomously (without human support or intervention) for a minimum of 72 hours
- transmit notifications to selected destinations in the event of non-nominal conditions.

When radar observations are taking place (and data are being collected) the radar stores all data and products in a local, on-board archive. The radar also has the capability of communicating quick-look images and other data to other computers on the local network, and if available, to a wide area network. In doing so, the GVSMR checks the validity of the data collected and distributed, and generates appropriate product metadata during data collection, product generation, and storage. The radar generates it products in at least one of the standard science data formats (e.g., netCDF), and its products are designed so that they can be directly ingested into the analysis software (Interactive Radar Information System, IRIS) available from the Sigmet company. The IRIS product is commonly used in for radar data analysis by the atmospheric sciences community. It is a goal for the GVSMR radar to generate and make available all of the polar coordinate and re-gridded products listed in Table 8-1 within 24 hours of observation.

8.5 GPM Project Contributions to Radar Instrument Operations

The GPM Project will provide the funds for the GVSMR radar operations, maintenance and sustaining engineering. It has not yet been determined at this stage of GVS development which organization will actually operate the radar. Options include operations within the Government, or contracted operations to another entity, for example, to a university. Those specific decisions will be made at a later point in the GVS life cycle. At present, it is clear that the radar operator will be responsible for all of the operations listed above, as well as for participation in pre-operational testing. The operator will also be responsible for the conduct of on-going configuration management of all radar systems and software, as well as all data holdings, documentation and computer code associated with the radar. An operational interface will also exist between the GVSMR radar and the archive and distribution (A&D) element of the GVS for all data, products, reports, documentation and computer code generated by or otherwise associated with the GVSMR.

9. GPM GVS Operational Scenarios

This section explores two use scenarios in which the GVS is employed in accomplishing basic GPM requirements for algorithm improvement and error estimation for global data products.

9.1 Operational Data Flow

This section provides a time-line that illustrates the nominal operations and data flow in the GVS. Section 4 examines GVS operations in the context of two use scenarios.

1. The PPS determines and periodically distributes scheduling information on GPM constellation and core spacecraft overflights of GPM GVS ground site locations. The GVS FCPG and the spacecraft measure the same precipitation events at the same time.
2. The GVS FCPG, the GPM core spacecraft, and the GPM constellation spacecraft measure precipitation events on an ongoing basis; the spacecraft measure events across the globe, while the GVS measures the events at local sites.
3. The PPS generates L1 and L2 data products for core and constellation spacecraft, extracts subsets of the data corresponding to GVS ground sites and VN locations, and delivers the subsets to the GVS A&D.
4. The FCPG sites generate data products that characterize the atmospheric state during a precipitation event. These data products are delivered to the GVS A&D.
5. Ancillary data providers (e.g., NOAA WSR-88D radars) generate products and send them to the GVS A&D.
6. The VN generates comparison products from using PR (pre-launch) and DPR (post-launch) data, and stores them in the GVS A&D.
7. The A&D distributes FCPG and VN data products to Precipitation Measuring Mission Science Team members and to the general user community.
8. The Precipitation Measuring Mission Science Team reviews and analyzes data received from the GVS A&D. Over time, the PMM Science Team proposes new GVS instrumentation and algorithms, which are tested and integrated into the GVS.

9.2 Pre-launch Algorithm Development

A PMM Science Team PI has plans to develop a new algorithm for snowfall retrieval from GMI microwave radiometer data. She joins the PMM working group on ground validation and conveys her GV measurement requirements to the GVS through that venue. A field campaign science plan is drafted by the working group. The science plan includes requirements for ground-based measurements of snowfall rates and particle size distribution, dual polarization radar measurements in several frequencies, and ground-based radiometer measurements. The plan also calls for microphysical and remote sensing aircraft measurements.

The cold-season field campaign is held in the winter of 2011-2012. Ground and aircraft measurements are collected, quality-controlled, and most data products are delivered to the GVS for archive. In some cases where the raw data products or model output are very large, the instrument or product PIs provide url's or other access information (e.g., ftp site IP addresses and directory information), and this information is provided to the GVS for inclusion in the A&D directory.

The PMM PI acquires ground and aircraft based data from the GVS A&D, and analyzes the results. She identifies several discrepancies in the assumptions she has made about the habit, size distribution, and density of hydrometeors as compared to the ground-based and airborne microphysical measurements collected during the campaign. She makes the adjustments to her assumptions, runs the forward radiative transfer code, and compares the results to the brightness temperatures recorded by ground-based and airborne radiometers. The results from her revisions yield a favorable reduction in model error. She runs the retrievals, and again the results compare favorably with ground-based measurements of snowfall rates and accumulation. The PI publishes her results and in a subsequent PMM Science Team meeting proposes that her algorithm improvement be implemented in the at-launch version of the PPS. After due consideration, this recommendation is accepted by the PMM Science Team.

GVS system elements needed in this scenario:

- GVS FCPG for field campaign measurement and product generation
- A&D archive, search and order
- GVS interface to the PMM Science Team for product request and delivery.

9.3 Post-Launch Product Validation

In 2012 NASA releases a NASA Research Announcement (NRA) for the PMM Science Team. Part of the NRA specifically solicits proposal for studies of retrieval errors, bias, and spatial error correlation.

One of the PIs has a successful proposal to estimate DPR precipitation errors using Validation Network data. At the time of launch, the VN has the capability of acquiring radar reflectivity and rain rate data from 6 national networks in the US, Canada, Brazil, S. Korea, Taiwan and the European Union. In all, 215 radars are part of the VN, 60% of which have dual polarization capability. The VN also routinely collects DPR data from the PPS for all 215 radars.

Analysis of VN metrics shows that, on average, the joint probability of a significant precipitation event occurring at one of these sites during a GPM overpass is about 1.5 per site per month. So three months following launch there are about 650 events for the PI to investigate.

The PI has his graduate student acquire VN match-up data from the GVS A&D. These data include DPR and ground-based radar reflectivity, rain rate, and median drop diameter (for the polarimetric radars).

The PI and the grad student analyze the data and find that the DPR algorithm tends to overestimate the precipitation rate in rain events over land. They publish their results and report on them at an algorithm workshop hosted by the PMM Science Team. Corroborating evidence also leads to the conclusion that the DPR attenuation correction algorithm is overcompensating for rainfall retrievals below the bright band. Adjustments are made to the algorithm, and subsequent comparisons to VN data indicate a better fit between the two estimates.

GVS system elements needed in this scenario:

- Delivery of PPS data products to the A&D
- A&D archive, search and order
- GVS interface to the PMM general users for product request and delivery
- Validation Network data product generation
- Generation and analysis of GVS metrics.

10. Acronyms and Symbols

ACRONYM	DEFINITION
3-D	3-Dimension
A&D	Archive and Distribution
ACRF	ARM Climate Research Facility
AGL	Above Ground Level
ARM	Atmospheric Radiation Measurement
ASCII	American Standard Code for Information Interchange
BUFR	Binary Universal Format for Representation of meteorological data
C3VP	Canadian CloudSat/CALIPSO Validation Programme
CART	Clouds and Radiation Testbed
CM	Configuration Management
CMO	Configuration Management Office
CoI	Co-Investigator
CONUS	Continental United States
CRM	Cloud Resolving Model
CSV	Comma-Separated Values
dB	Decibel
dBZ	Reflectivity Factor in Decibels
DOE	Department of Energy
DPR	Dual-frequency Precipitation Radar
DSD	Drop Size Distribution
EOP	Extended Operation Period
FCPG	Field Campaign and Product Generation Function
GCE	Goddard Cumulus Ensemble
GCM	Global Climate Model
GMI	Global Microwave Imager
GPR	Goddard Project Requirement
GPM	Global Precipitation Measurement
GPS	Global Positioning System
GRIB	GRIdded Binary
GSFC	Goddard Space Flight Center
GV	Ground Validation
GVS	Ground Validation System
HDF	Hierarchical Data Format
HMT	HydroMeteorology Testbed
hr	Hour
ICD	Interface Control Document
ID	Identification
IFOV	Instantaneous Field Of View
IOP	Intensive Operation Period
JAXA	Japanese Aerospace Exploration Agency t
K	Kelvin

ACRONYM	DEFINITION
Kdp	Specific Differential Phase
km	kilometer
km	Kilometer
L2	Level-2
LDM	Local Data Manager
LDR	Linear Depolarization Ratio
m	Meter
MAR	Mission Assurance Requirements
mb	millibar
MD	Metrics Database
mm	Millimeter
ms^{-1}	Meters per second
NASA	National Aeronautics and Space Administration
netCDF	network Common Data Form
NEXRAD	Next Generation Weather Radar (a.k.a WSR-88D)
NOAA	National Oceanic and Atmospheric Administration
NPR	NASA Program Requirement
NWP	Numerical Weather Prediction
NWS	National Weather Service
PI	Principal Investigator
PMM	Precipitation Measuring Missions
PPI	Plan Position Indicator
PPS	Precipitation Processing System
PR	Precipitation Radar
QC	Quality Control
RT	Radiative Transfer
rZdr	Resampled differential reflectivity factor
rZh	Resampled equivalent reflectivity factor horizontal polarization
rZv	Resampled equivalent reflectivity factor vertical polarization
SHEF	Standard Hydrometeorological Exchange Format
SSM	Model-Based Analysis
Tb	Brightness Temperature
TOA	Top-Of-Atmosphere
TRMM	Tropical Rainfall Measuring Mission
UF	Universal Format
UHF	Ultra High Frequency
US	United States
UTC	Universal Time, Coordinated
VCP	Volume Coverage Pattern
VN	Validation Network
WRF	Weather Research and Forecasting
WSR-88D	Weather Surveillance Radar - 1988 Doppler
XML	Extended Markup Language
Z	Reflectivity Factor

ACRONYM	DEFINITION
Zdr	Differential reflectivity factor
_dp	Differential propagation phase
_hv	Co-polar correlation coefficient